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A CASE STUDY OF THE STRESS - RESPONSE ENVIRONMENTAL STATISTICAL SYSTEM: The Laurentian Lower Great Lakes

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I. INTRODUCTION

1. Statistics Canada has had a program in environmental statistics since 1973. Its main projects have been in the development of a conceptual framework for environmental statistics (STRESS) and in the publication of a compendium of bureau data on human activities impacting the environment.(1) These data were compliled for all of Canada by watershed areas.

2. In order to become more familiar with the requirements for environmental statistics suggested by the STRESS framework, the Bureau underbook a case study of the Laurentian Lower Great Lakes Region, with a focus on the transformation in the aquatic ecosystems as a result of human activities. The main goals of the case study were:

(1) To provide the Bureau with sufficient exposure to environmental monitoring data to suggest both the nature and variability inherent in such data and the ways in which such data might eventually be integrated with economic and social data.

(2) To provide an assessment of how feasible it might be to reorganize the Bureau's statistical compendium (Human Activities and the Environment) in terms of the conceptual framework underlying STRESS.

(3) To identify current data deficiencies particularly with respect to data on environmental transformation and human responses as specified in the conceptual framework.

(4) To provide a vehicle for translating the conceptual framework into operational terms. In so doing, the ambiguities and limitations of the conceptual framework might be better understood.

3. This case study report on the Lower Great Lakes did not in fact deal with all the elements of STRESS, but with a major portion of them as indicated in Table 1. In undertaking the study of this region for the purposes listed above, the primary emphasis was of course on the development of operational stress taxonomies rather than ecological relationships per se. To the extent that ecological relationships are discussed the intent is to illustrate the nature of the concepts involved in the STRESS taxonomies.

4. The STRESS conceptual framework was presented in 1978 to the Meeting on Environmental Statistics, Statistical Commission and Economic Commission for Europe (CES/AC 40/14: ENV/AC, 6/R.6, 16 December 1977). The delegates while favorable towards the conceptual framework expressed reservations concerning the scope of the framework and the need for more operational definitions within the STRESS taxonomy. The case study was an effort to overcome these limitations and provide experience in environmental statistics for a specific region which would facilitate future restructuring of bureau publications in the area of environmental statistics.

(1) Human Activity and the Environment, Statistics Canada, Cat. 11-509, March 1978.
Towards a Comprehensive Framework for Environmental Statistics, A Stress - Response Approval, Statistics Canada, Cat. 11-510, May 1979.

II. SCOPE AND LIMITATIONS

5. The purpose of the Lower Great Lakes Study is to test the feasibility and appropriateness of STRESS for the development of a general statistical data base on the environment. To accomplish this objective, it was considered necessary in the first instance to evaluate and assess the available socio-economic data base in the context of stress factors as identified in the case study model. At the same time a sufficient set of response indicators to characterize the ecological transformation of the Lower Great Lakes was to be identified.

6. Further, secondary objectives were to assess the efficacy of the "reference frame" to integrate the scattered data from different sources into a coherent general information system, and to reveal the anomalies in the proposed taxonomies of STRESS.

7. It must be kept in mind, however, that this is a partial study of the STRESS taxonomy, with particular emphasis on the organization of stress data associated with qualitative changes in the Great Lakes from an ecological health standpoint. Quite clearly other environmental concerns, such as the environmental impacts on human health, and qualitative and quantitative assessments of natural resources in the watershed of the Lower Great Lakes were excluded from the study. Table 1 portrays the overall structural framework for STRESS and indicates the partial nature of the case study. Figure 1 portrays those elements of the structural framework which form the core of the case study.

8. Some of the considerations that determined the choice of the project model were, first the desirability of an ecosystem approach, thus focusing on the fundamental question of environmental transformation and providing an opportunity to test STRESS from an ecological perspective. Second, the availability of data was considered of paramount importance and the Great Lakes region appeared likely to fulfill this criterion. Thirdly, STRESS is not only an organizational framework for environmental data but also a decision-making tool. The degradation of the Lower Great Lakes is of considerable national and international concern, and the case study might throw fresh insight on the use of data for policy purposes.

9. The choice of model also contained certain risks, not the least being the paucity of scientific knowledge of the underlying forces of ecosystem transformation in highly complex multiple stressed areas such as the Lower Lakes. Moreover, once having embarked upon this pioneering effort, inadequacies became evident. First, by focusing upon aquatic ecosy interactive relationship between man and his environment was to sor left out. Secondly, the choice of an international study area com efforts to draw together an adequate and balanced set of statistic an obvious bias favoring data obtained from Canadian sources.

III. AN OVERVIEW OF STRESS

10. The conceptual framework underlying STRESS has been desc and it suffices for current purposes to summarize its basic caution the reader on several points.(3)

11. First, the qualifiers, for these are critical for its proper evaluation. STRESS is a system of classification of environmental information and not a model of man-environmental behaviour. Naturally, there are elements of at least partial models of this sort that govern the choice of structure for STRESS and the particular types of data thought to be most relevant. However, for the region as a whole, to the extent that STRESS is concerned with stress-response of ecosystems, it is "black box" in concept. It yields not mechanisms, but data organized in a framework to provide overviews of environmental change.

12. Second, a cautionary note that applies to all classification systems, be they economic, biological or sociological; namely that all such systems are predicated to some degree upon breaking up the continuity of nature into discrete forms. These forms constrain as well as facilitate our interpretation of nature.

13. Although it is recognized that classification rules for STRESS must at some time be formalized, a flexible approach keeping some alternative options open is preferred at this stage. It is our hope that by further elaboration of STRESS the nature of the data and its relationship to the underlying concepts will become increasingly clarified, thus laying the foundation for a sound statistical taxonomy required to establish a data base on the environment.

14. STRESS is a framework for organizing statistical data using three fundamental sets of criteria; those of integration, those of activity differentiation, and those of spatial coherence. The latter was largely already implied in the terms of reference of the case study, i.e. the Lower Great Lakes Watershed, therefore is excluded from critical examination in this study. "Integration" refers to the behavioural characteristics of the system and associates stress factors with those of response. It must be recognized, however, that only in rare instances is it possible to map a one-to-one correspondence between stress and response (i.e., traditional cause-effect relationship) and the normal situation is a more vaguely defined many-to-many "associative" linkage. From a taxonomic standpoint it is essential to recognize the role of concepts, definitions (and even conventions) that enable one to distinguish stress factors from those of response. The need for "activity differentiation" stems directly from the essential feature of STRESS as an "activity based framework". This requires, inter alia, an "activity taxonomy" characterized by major types of stress. Thus, "production and consumption" are viewed as an activity generating waste residuals, "capital formation of tangible assets" as an activity permanently restructuring the environment, "agriculture, fishing, etc." as a harvest activity which stresses the renewable resource base. The whole system is predicated on what might be referred to as a dialectical process model which by analogy can be viewed as follows: the activities statistics measure the given background state from which stresses arise (stress statistics), these in turn transform the state of the environment (response statistics); man, through collective or individual actions, creates counter-measures in his attempt to modify the stressful effects -- and to the extent he succeeds, a new relationship between man and nature is obtained. Moreover, in the absence of the unlikely event of a "steady state" situation, new disequilibriums between man and nature emerge, setting in motion further counter-measures, thus continuously within its structure the potential of dynamic disequilibrium condi-

15. To be of maximum utility to environmental managers, the data base must be designed for the production of indicators of environmental trends and their spatial distribution. STRESS provides the structural frame for these indicators. While the critical process of selection of particular indicators reflects current perceptions of the nature of environmental transformations, our understanding of these complex systems is rapidly evolving and so too will the choice of indicators. STRESS may aid this process by itself promoting better understanding of the pattern of inter-relationships between man and nature.

IV. THE LOWER GREAT LAKES CASE STUDY AREA

16. Geographically, the case study encompasses the region bounded by the Lower Great Lakes aquatic systems (Lake Erie and Lake Ontario) and their surrounding watersheds (Figure 2). However there is an important spatial asymmetry with respect to the documentation of stresses and responses within the case study. With respect to stresses, activities within the watershed or within the aquatic system are included. However, with respect to the response side, by and large, only indicators of response pertaining to the aquatic systems are documented.

17. These geographical boundaries, it will be recognized, are somewhat arbitrary. It is known, for example, that stresses in the Great Lakes may originate from activities well beyond the water and airsheds of the region. Pollutants entering the Lower Great Lakes via mechanisms of Long Range Atmospheric Transport or via drainage from the Upper Lakes illustrate this type of consideration. Further, since consumption and storage activities, as well as production have environmental impacts, production anywhere in the world economy can potentially have stress effects in the Lower Great Lakes. There appear few satisfactory ways around this dilemma except to establish boundaries that suffice from some points of view e.g., that provide an environmental perspective for local activities, while recognizing that these boundaries fail to capture all such agents responsible for transformation.(4)

V. STRESS-RESPONSE TAXONOMY

Stress Categories

18. The classification of human activities developed for purposes of the case study while consistent with the overall structural framework for STRESS (Table 1) involves some modifications to accommodate the particular features of the case study.

19. With respect to Population and Aggregate Human Activity, we have included in addition to population, and economic activity indicators, two measures--watershed land use and water use, which serve in the context of the pressures on the Lower Lakes aquatic ecosystems as surrogates for aggregate stress. These categories however, in other contexts might well be placed elsewhere in the taxonomy. With respect to Generation of Waste Residuals, we have included aspects of concerns over Energy Use and Environmental Contamination.

20. The data on the stress side consist of two major groups - activity statistics (based on a stock-flow concept), and stress indicators. Activity statistics refer to consumption, production and accumulation of man-made stock that have potential for stress on the environment. Stress indicators refer to the stresses from economic (and natural) activity, and are generally obtained from monitoring records, notably measures (or estimates) of pollution loads. The latter can be further subdivided into - point source, i.e. stresses which enter the environment form specific points, and diffuse source, i.e. stresses on the environment which enter diffusely via the water and airsheds. Agricultural runoff, which carries phosphates and other nutrients as well as toxic substances is an example of a diffuse source stress.

26. Table 2 summarizes the data content on the stress side of the Case Study. The main features of the stress taxonomy are described below.

27. Economic and demographic data which have a critical but indirect bearing on the transformation process were placed in a category "population and aggregate human activities". These data comprise of historical trends in population growth and its distribution; land use (subdivided into urban and rural land use categories including developed land (residential, industrial and commercial), agricultural land (cropland, pasture) and non-agricultural (wildlands, forests, and other) (5); economic activities comprising the total output of major economic sectors and their use of various materials and supplies. Here, physical measures of production would be more appropriate than the surrogate measures of "real output" (in monetary terms) and employment. Moreover, to reflect the shift in technology employed process oriented statistics would be required. One aggregate measure which makes the attempt to include an aspect of the intensity of resource use is the concept of demophoric growth -- defined as the growth in population in terms of an energy consumption equivalent. While this concept as currently developed does not differentiate among types of energy consumption (which may have very different environmental impacts), it does represent an initial effort to reflect overall pressures on the region with a combined technological and population component.

23. Generation of Waste Residuals includes activities leading to the point source and diffuse loadings of nutrients, toxins, heat, radiation, etc., into the Lower Great Lakes Watershed. Although the loadings data are based upon estimates of human loadings, it is important to recognize the importance of non-human sources of these loadings, particularly with respect to phosphorus where in some instances non-human sources are substantial.

24. Permanent Environmental Restructuring involves direct physical alterations to environment. In the context of the Lower Great Lakes, drainage of wetlands, construction of dams and canals, and shoreline restructuring have had significant impacts on the aquatic system.

25. Harvesting of Renewable Resources refers to forestry, agriculture and fisheries. The Case Study concentrated on the harvesting of fishes, since these activities most directly alter the Lower Great Lakes aquatic ecosystems.(6)

26. Natural Geophysical Activity refers to various climatically induced or physically induced events. One example in the Great Lakes region is the slight warming trend detectable over the past fifty years or so which has significant implications for those species of fish and other taxa that are at the southern limits of their range. Another example is periodic storms which may have significant repercussions for the biota of the lakes. Assessments of trends in water quality parameters, as well as changes in the composition and relative abundance of biota, must take into account these periodic disturbances, particularly for the near shore zone.

27. The classification of activities into the above five categories organizes data in a manner which reflect both major environmental concerns and to some extent the different pathways by which the environment becomes transformed. Each pathway may have some unique features which warrant separate consideration in analysis, thus for example, changes in climate exert very diffuse and widespread effects on the biotic component while generation of waste residuals affects a narrower group of "pollution sensitive" species, including man. Environmental restructuring in the Lower Great Lakes context involves reduction in suitable habitat (particularly with respect to fish and birds) and also may bring about the unintended introduction of new species (exotics) which can destabilize the exisiting biotic communities (7). This occurred, for example with the invasion of the sea lamprey from the Lower Great Lakes into the Upper Lakes via the Welland Canal.

Response Categories

28. Referring again to the Structural Framework for STRESS (Table 1), the Case Study attempted to document aspects of three major groups of response indicators (ecosystem health, environmental contamination and renewable resources, particularly harvesting) and in addition make reference to aspects of human health and socio-economic responses. These response indicators are not for the most part associated uniquely with specific human (and natural) activities, as portrayed in our earlier publication on the conceptual framework (SC 11-510). Rater the environmental response indicators reflect the complex and often synergistic effects of a number of stresses. This is not to preclude, or course, that some response indicators may well be specific to a single type of stress. In such cases, the response indicators might be considered diagnostic of specific stresses. In the more general case, in which the response indicator integrates accross many factors, including natural and human stress--the response indicator may be considered an "integrator" of the environmental stresses.

29. There are a number of criteria for an ideal set of response indicators that adequately reflect changes in the health and viability of the natural environment. Response indicators should be, in so far as possible, holistic in concept (that is account for change at an ecosystem rather than the component population level), be responsive to multiple stresses in heavily abused systems as in the Lower Great Lakes, and be sensitive to specific stresses in less complex situations.

30. Another aspect of response indicators is the degree to which they are "leading" or "lagging" changes in the state of the environment. For policy, "leading" or "early warning" indicators are obviously preferred. In some cases changes in a local area may foreshadow changes in the larger region. For example, nutrification in the bays of the Lower Lakes may foreshadow changes in the offshore waters. Unfortunately, since "leading indicators" for the environment are not yet well established, most response measures adopted for the case study describe the state of the environment in a retrospective mode.

31. Our approach to structuring the response side thus reflects a compromise between ideal criteria for response indicators and available monitoring data. We propose a general classification for environmental monitoring data that incorporates basic aspects of ecosystem health, levels of environmental contaminants and quality renewable resources. Response indicators, as shown in Table 3, reflect an ecosystem health taxonomy which is related only in a general way to the generic terms used in Table 1.

32. The ecosystem health taxonomy comprises information pertaining to the following five elements: (1) Primary productivity or the rate of energy fixation and transfer within the ecosystem; (2) nutrient availability and cycling within the abiotic and biotic compartments of the system; (3) the composition of the biota (relative abundance and diversity); (4) the quality of the biota (e.g. contamination, stuntedness, etc.); and (5) the quality of environmental media. Community ecology has advanced to the state where there now exist methodologies for representing these attributes at the whole system level.

33. Table 3 portrays the response classification utilized in the Case Study to integrate environmental monitoring data from a variety of sources. We describe first the general categories adopted for the response side relegating to a later section a description of the specific indicators.

(1) Primary Productivity is a measure of the effective conversion (per unit area) of solar radiation to living biomass. Primary productivity, in general, is affected by such factors as the incident solar radiation, nutrient availability, spectoral characteristics of the plants and the atmosphere, toxic contamination, and climatic variables such as rainfall etc.

(2) Nutrient Availability and Cycling is descriptive of the turnover and recycling of key nutrients in the system. Methodologies for representing the seasonal flux in nutrient concentrations and their rates of turnover are being developed, although they have yet to be applied in a satisfactory way to large systems. With respect to aquatic systems, measures of inflow and outflow of nutrients (turnover rates) are for the most part in an embryonic stage of development. Existing water quality monitoring data, for example, usually include only measures of nutrient concentrations rather than the rates of turnover.

(3) Composition of Biota This aspect of natural systems is usually documented in terms of species lists for impact assessment statements. Such detailed information often frustrates rather than impresses decision makers. While not negating the importance of "indicator species" in signaling environmental change, aggregate measures of the biota in terms of community composition provide the overviews difficult to achieve on the basis of

34. Community composition can be described in terms of "functional species groups" based on ecological roles served by species. Thus, shifts in the relative importance of "functional groups" are generally far more significant environmentally than changes in individual species, for such shifts may signal a basic change in the structure and function of the ecosystem.

(4) Quality of Biota This loosely defined category includes information pertaining to (1) contaminants in biota (2) changes in the size of "important" species (a number of factors such as overharvesting, contamination etc. may serve to reduce the size of dominants) (3) changes in the disease incidence of key biota.

(5) Quality of Environmental Media Quality of environmental media in the Case Study refers to the contamination in the abiotic compartments of the ecosystem. Quality of environmental media indicators usually refer to contamination of air, land and water. As shown in Table 3, this particular aspect is only one of five major descriptive features relating to the state of aquatic ecosystem health.

VI. THE CASE STUDY DATA BASE

Sources of Data

35. One of the main objectives of the case study was to assess the degree to which existing data relating to human activities and environmental responses could be integrated within the structural framework for STRESS. To examine this possibility various economic, demographic and environmental data were selected from existing sources.

36. No data base currently exists on the Lower Great Lakes region which contains comprehensive information on all aspects germane to STRESS. Furthermore, no single source of information (including the prodigious efforts of the International Joint Commission from which we have drawn freely) supplies more than a fraction of the relevant data. As shown in Tables 2 and 3, information on environmental aspects of the Lower Great Lakes is found in a diverse group of publications including reports of provincial, federal and state agencies; the International Joint Commission; The Great Lakes Basin Commission; and the Great Lakes Fisheries Commission. In addition, research studies that were part of the International Field Year for the Great Lakes program (IFYGL) contributed to the case study data base.

Temporal and spatial coverage

37. The temporal and spatial coverage of the case study data base is summarized in Tables 4 and 5. Spatially, the stress and response elements of the Case Study do not overlap. The stress data are keyed to terrestrial based administrative units (counties, provinces, states, planning areas, watersheds) while the response side covers regions of the aquatic system (e.g. basins, shorelines, bays, etc.). This spatial complementarity between the stress and response data reflects the focus of the case study--namely the documentation of human activities in the watershed and the patterns of transformation in the Lower Great Lakes Aquatic system.

38. Stress related data are available for periods of thirty years or more in many instances (Table 4) while response related data (Table 5) are with few exceptions confined to the recent decade.

39. While it may be said that the primary purpose of the case study was to demonstrate the feasibility of utilizing the STRESS framework for organizing environmental information, and assessing the availability of data, the question of the quality of information is also relevant (particularly with respect to the response side). Environmental monitoring data are not so well consolidated as are the stress data. For example, a number of important water quality parameters for the Lower Great Lakes are in the process of being "worked up" in an attempt to more clearly reveal trends and separate signal from noise.(8)

40. With respect to stress factors, information on overall pressures (population, land use, industrial activities) appear far more reliable than information on pollution loadings (derived from ad-hoc studies such on PLUARG). Data on point source discharges are of generally greater reliability than are the data on diffuse source inputs.

41. In summary, there are a number of concepts within the structural framework of STRESS which can be represented by the available data. Much of the response data, however yields as yet rather fragmentary information. Further, the quality of these data are uneven, some series (such as phosporus concentrations) being relatively reliable, while other series (such as chlorophyll a) requiring further development to render the data useful for purposes of environmental assessment. With respect to the stress side, relatively good quality data exist for demographic and economic measures such as aggregate population and activity statistics, while the data are sparce with respect to physical measurement of stress.

VII. TRANSFORMATIONS IN THE LOWER GREAT LAKES ENVIRONMENT

42. There are a number of reports describing various features of the transformation process in the Lower Great Lakes aquatic ecosystems (9). It is neither our intention to summarize these documents , nor to provide yet another such description. Rather, we provide a description of transformation in terms of the structural classifications of STRESS in order to furnish an example of the kinds of information that might be included within STRESS.

43. Since most environmental response data are of recent origin, it is difficult to gain a perspective from these sources alone of the substantial transformation that the lower Great Lakes has undergone under the influence of now more than a century and a half of intensive cultural stress. Historical studies,(10) suggest that before the onset of European settlement, the Lower Great Lakes were in many respects very similar to the environment prevailing in the Upper Lakes today. The offshore waters were of low fertility and provided cool and cold water habitat throughout the year-- and even in mid-summer, ample cool and clear waters were provided by stream flow. Shallow water habitat consisted of a profusion of diverse wetlands, and pristine bays and river mouths. Further, it is estimated that as much as 50% of the total fishery consisted of individuals in excess of 5 Kilograms in weight, and many of these in the highly desirable species categories. Common pest species of today (alewife and carp) were absent, and the Sea Lamprey was confined to the waters of Lake Ontario.

Aquatic Ecosystem Transformation

44. Primary Productivity: As indicated in Table 3, we have selected the plant photosynthetic pigment chlorophyll a to serve as an indicator of primary biomass, reflecting (rather loosely) the potential productivity (or energy fixation) of the primary producers in the ecosystem. Case study data for this indicator are summarized for lake basins in Tables 6 and 7, and for nearshore zones in figure 3.

45. While chlorophyll a data for offshore zones are far too variable to yield trends, a scan of peak concentrations (as given in Tables 6 and 7) suggests that both lower lakes are highly nutrified (eutrophic) (a fact easily corroborated by the studies of changes in the type of algae now found in the lakes). This contrasts sharply with conditions in these waters prior to the onset of cultural stress.(11) Nutrification resulting in higher ecosystem productivity is in this case a reflection of degraded environmental conditions since these systems now support less valued fisheries and are characterized by blooms of nuisance algae over much of the nearshore region.

46. The nearshore survey (fig. 3) indicate that the localization of high areas of productivity are associated with the urban and industrial centers. Thus high nearshore chlorophyll a values are found near Burlington, Toronto, and Oshawa. A similar comment can be made with respect to the nutrient status of the shoreline of the Great Lakes region in general, although here one must also take into account differences in shoreline slope, erosion, natural sources of nutrient inputs etc.

47. Nutrient availability and cycling: Phosporus concentration appears to be the primary factor determining the nutrient status of the Lower Lakes. The elevated level of phosphorus in the Lower Lakes as a result of human activity is shown by data on: a) the concentration of phosphorus in offshore waters (Tables 6 and 7, Figure 4); b) the concentration in selected basins and bays (Figure 5) and c) the nearshore concentrations for Lake Ontario (Figure 6).

48. In the offshore waters of Lake Ontario, the recent trend has been slightly downwards with respect to the average concentration of Total Spring Phosphorus (Figure 4). Nonetheless, by historical standards (Figure 5), current levels in basins and bays of the Lower Lakes are still extremely high. Further in nearshore areas, the distribution of phosphorus is relatively uneven (Figure 6), reflecting in large part the spatial distribution of human activities. Highest phosphorus concentrations are found near major point source discharges at Toronto, Oakville, Hamilton, Niagara on the Lake and Oshawa. To some extent higher concentrations in the nearshore zone may reflect biological mechanisms for retention of nutrients as well as possible physical factors having to do with the degree of mixing of nearshore and offshore waters.

49. Oxygen: Oxygen depletion (anoxic conditions) has been a serious problem for a number of years in local areas of the Lower Lakes (Bay of Quinte, Burlington Bay) and in the relatively large but shallow central basin of Lake Erie. In these stratified basins or bays (in which the cooler bottom waters do not mix in summer with the upper well oxygenated system) bottom waters can be seriously depleted in oxygen with significant consequences for the entire lake biotic community (12). This occurs to some extent under natural conditions, but is greatly exacerbated under conditions in which human activities add substatially to the biological oxygen demand, as happens, for example, with nutrification of these waters, through pollution loadings.

50. The history of oxygen depletion in the relatively shallow central basin of Lake Erie indicates deterioration of oxygen conditions since 1929. In 1928-30, dissolved oxygen concentrations in the central basin were below 5 mg/l. In 1958, indications of extensive anoxia appeared in the central basin with concentrations in the 1-3 mg/l range. In August, 1960 the western 2/3 of the central basin had values of less than 2 mg/l. Surveys in 1973-74 of the hypolimnion in the central basin confirmed the continuation of anoxic conditions in mid-summer--as do data from 1978. This serious oxygen depletion for this region of Lake Erie has no doubt contributed to the popular notion that Lake Erie is "dead". While not of course literally true, many forms of life have been affected by the anoxic mid-summer conditions in the central basin, including the sensitive larvae of the Mayfly, now locally extinct after an unusual bout of anoxia in 1953. Fish extinctions in Lake Erie have also been in part attributed to anoxia of the bottom waters (13).

51. Composition of Biota: Biotic transformations are documented in the Case Study for three major aquatic ecosystem components: fish, phytoplankton and benthos. Of these, the most complete data are for fish, primarily because of their considerable economic importance.

52. Commercial fish species of the lower lakes can be grouped by size and habitat. Benthic fish (comprising generally large fish) are restricted to nearshore and offshore bottom waters; large pelagic fish are found in offshore surface waters; small pelagic fish--comprise the smaller fish found in the offshore surface waters. From the point of view of commercial fisheries, the most valued and accessible fish were the large benthics of the nearshore zone followed by the larger offshore fishes and finally the smaller offshore species (14).

53. In Tables 8-9 trends in the composition of the commercial catch are given in terms of these species groupings. In general the commercial catch has shifted from the large (more valuable) benthic fish to the small (least valuable) pelagic fish.

54. It is recognized, of course, that some caution must be used in inferring the changes in the underlying fish stocks from the commercial catch data. Obviously, the commercial catch statistics reflect in part the economic viability of the fishery which is a function of both the availability of fish and technology and market price structures. For example, one factor which may explain the increased commercial catch of the small pelagics is improved fishing gear (gill nets made of synthetic fibers which were stronger than cotton used previously were introduced in the early 1950s) permitting higher efficiency in the capture of the small offshore pelagics.

55. These biases in the commercial catch statistics caution against inferring any direct relationship between the commercial catch data and the underlying stock of fish in the lakes. Yet, the commercial catch data do correspond to more direct estimates of fish stocks in the Lower Lakes obtained from surveys carried out under the International Field Year of the Great Lakes (IFYGL) program (15). As shown in Table 10, the fishery in Lake Ontario were comprised mainly of small pelagics (mostly alewife and rainbow smelt in the open waters) and some larger pelagics in the nearshore zones (white and yellow perch). The virtual absence of large benthic fish in the survey is striking, and contrasts with historical commercial fish catch data.

26. The fish community of the lower lakes can also be described in terms of shifts from native fauna to the more aggressive recently introduced species. These changes are recorded in Tables 11 and 12. In both lower lakes, extinct species tended to be commercially highly valued fishes, while for the most part, the introduced species are of low commercial value (e.g. alewife, carp). In fact, the latter species are not yet significant components of the commercial catch.

57. Changes in the abundance and composition of algae are also indicative of changing conditions in the environment of the lower lakes. The most publicized indicator in this area is the growth and abundance of the filamentous alga-Cladophora. This nuisance alga was first noted in the Toronto area of the lower lakes in the 1930's. Within twenty years its distribution had spread so that it now forms a lush biomass on the open wave swept shorelines of Lake Ontario, as shown in a recent distribution survey (Figure 7). Near the Bay of Quinte, Cladophora covered approximately 30% of the shoreline, displacing a much more diverse community of algal forms (diatoms) which inhabited similar substrate.

58. Algae can also be examined in terms of species groups--characteristic of the overall nutrient status of the lakes. Certain groups of algea are prominant in waters with low nutrient status while other groups require elevated nutrient levels for their survival. The Cyclotella associations for example that characterize lakes of low nutrient status were once extremely important in Lake Ontario. However, in the 1972/73 IFYGL survey, this group was found only in trace amounts, having been replaced by a phytoplankton assemblage characteristic of high nutrient conditions (Asterionella formosa, Diatoma elongatum, and Fragilaria crotonensis).

59. The fauna of the lake bottom (Benthic organisms) are also sensitive in their species composition to changes in nutrient condition and many other environmental factors, such as presence of toxins, oxygen deprivation etc. The sudden appearance or disappearance of oligochaete species (worms) may signal fundamental changes in the aquatic ecosystem.

60. In the survey of oligochaetes for Lake Ontario (also carried out under the IFYGL program) there are correlations between species associations and urban centers. For example, one species (T. tubifex) is present in high concentrations in waters adjacent to Toronto, Burlington, and other urban centers, while another species (Stylodrilus) is absent in areas near the urban centers, yet this species dominates the benthic community in most other regions of the lake.

61. Various indexes of pollution based on the relative abundance and composition of the benthic community have been proposed. According to one criteria, severe pollution is indicated by oligochaete densities in excess of 5000/m2 whereas the absence of organic pollution is indicated by oligochaete densities below 1000/m2. According to these criteria, a majority of the shallow water areas in Lake Ontario were severly polluted in 1972-73.

62. Another pollution index makes direct use of the composition of the benthic community (16). Using this measure, "highly perturbed conditions" prevail when the oligochaete species are dominated by the pollution tollerant form L. hoffmeisteri. Six shallow water areas of Lake Ontario were classified as highly perturbed during the IFYGL survey under this criteria.

63. Quality of Biota: Contamination of fish has caused commercial fishing closures for certain Lower Lakes fisheries and the issue of guidelines for human consumption of fish taken from these waters. In Lake Ontario, the mature coho salmon running the Credit River in the fall of 1975 contained PCB's concentrations up to 23 ug/g fish flesh--well in excess of the guideline of a maximum of 2 ug/g edible portion of fish. Further, carp, smelt, the American eel and all Lake Ontario salmonids have been found to contain excessive PCB's. Table 13 documents the status of restrictions due to concentrations of Mirex, PCB's, DDT and mercury in Lake Erie fish.

64. A more extensive listing of contamination in fish in the Canadian waters of the Lower Lakes indicates that for Lake Ontario, excessive concentrations of mercury, PCBs, Mirex and DDT were found in coho salmon, rainbow smelt, brown trout, chinook, brown mullhead, white sucker, white bass, yellow perch, northern pike, white perch, smallmouth bass and American eel. Mercury contamination was high for carp, northern pike, largemouth bass, smallmouth bass, walleye and channel catfish. Larger fish in general contain higher concentrations of toxic substances, prompting consumption guidelines based on size classes.

65. Contaminants found in birds (resident herring gull colonies) are shown in Table 14. These data form part of an extensive data base involving a number of avian species and a large group of toxic substances. Herring gull eggs show high mean concentrations of DDT, DDE, Mirex and PCBs. There is however considerable variance in these data. This variability is due in part to the small number of eggs sampled from each colony. Nevertheless, a reduction in contaminant levels in Lake Ontario gull eggs over the period 1974-78 seems evident. A less significant reduction occurred in Lake Erie populations, (perhaps because in most cases these populations already had relatively low levels of contaminants at the beginning of the monitoring period). Lake Ontario gull populations indicated contaminant levels 2-3X the levels found in Lake Erie gull populations. Recently, the deadly poison Dioxin has been found in sufficient quantities in Lake Ontario to be detected in Herring Gull eggs.

66. Quality of Environmental Media: Contamination of the Lower Great Lakes aquatic ecosystem is pervasive. Extremely high concentrations of PCB's, lead and mercury are found in the surficial sediments of these waters. The rates of deposition of mercury and lead in Lake Ontario have increased dramatically with the onset of settlements (sample data for Mercury shown in figures 8 and 9). Waste dumps which drain into these lakes may remain a source of PCB's and other toxic materials long after new sources of inputs are curtailed.

67. The general distribution of PCB's in the Lower Lakes is correlated with centers of industrial activity, particularly the regions adjacent to Detroit. Cleveland and Rochester. High concentrations of toxic substance generally found in the eastern part of Lake Ontario and the tendency for highest concentrations to be found near the southern shores of the Lower Lakes, reflect also to some extent the patterns of sediment transport in these waters.

Socio-Economic Responses

68. The Value of the Commercial Fish Catch: One direct consequence of transformations in the lower lakes on human welfare is a change in the availability of the highly valued fish stocks. As shown in Tables 15-16 the shift in the commercial catch from high valued to low valued fish stocks is striking. In the Canadian waters of Lake Ontario, the percentage of the commercial catch that comprised high valued species fell from 18.4% in 1953 to 0.3% in 1976. In the American waters of Lake Ontario, a similar trend was evident with high value species declining from 46.8% of the total catch in the period 1935-39 to 27.3% in 1977. In the more productive fisheries of Lake Erie a similar pattern was evident, with the percentage of high valued species falling from 18.5% in 1953 to 1.1% in 1976 in Canadian waters, and from 60.6% to 3.7% in U.S. waters over the period 1935-77.(17)

69. Human Health: The structural framework for STRESS includes provision for documentation of the environmentally related aspects of changes in human health. The case study, however, as already mentioned was a partial study of STRESS and this aspect was not included. However, the potential for incorporating health data in STRESS does exist, with the availability of morbidity data by region, classified in terms of environmentally related diseases.(18) Evidence now suggests that people living in the Great Lakes Basin are exposed to health risks greater than the U.S. national norms for a number of environmentally related diseases.(19) The causes are likely complex synergistic effects of contaminants in air and watersheds as well as in the food supplies (e.g., contamination in the fishes of the lower lakes discussed above).

Collective Responses

70. Collective and individual responses refer to policy actions, either protective or curative to maintain or rehabilitate the environment. The basic policy framework for the Great Lakes reflects the complex and overlapping array of administrative jurisdictional boundaries, involving legislation at international, federal, state, provincial and municipal levels. International, or more precisely, bi-national coordination is provided through the International Joint Commission and the Great Lakes Fishery Commission. The Great Lakes Water Quality Agreements of 1972 and 1978 provide a legal framework at the international level for reducing pollution stresses on the Great Lakes. Provisions in this agreement have encouraged actions to reduce point source nutrient and toxic loadings, as well as recommendations to reduce non-point source discharges into these waters. The 1955 Canada - USA convention on Great Lakes Fisheries signed by both heads of state specified the objective of rehabilitation of valued fisheries.

71. The limitation of the scope of the study virtually excluded consideration of the potential data on "Collective and Individual Response". The remarks below give an indication of the kind of data that would be included in this category.

(1) Loss of Recreational Potential: This would document the shifts in recreational use patterns including data on beach closings, changes in the use of waters for sports fisheries etc. In the Bay of Quinte, for example, with increased eutrophication there has been a decline in the use of the bay for sports fishing, and a decline in tourist trade--especially from New York State.

(2) Costs of Pollution Abatement: This would include data obtained in surveys of capital and operational expenditures associated with pollution abatement; e.g. municipal and industry costs of sewage treatment plants, holding tanks for effluents, stack scrubbers (for electrical generating stations) etc.

(3) Data on legal restrictions: Tables 17 and 18 provide background information of "collective response" resulting from the concern to protect and rehabilitate the Great Lakes. To document the "feedback loop" between state of the environment and man's response to environmental degradation data would be sought on restrictions of shoreline land use, restrictions on fish consumption, restrictions on the use and disposition of potentially harmful substances, etc. In addition, complementary data on the cost of implementing these control, would also form part of the data base.

VIII. HUMAN ACTIVITIES AND THE GREAT LAKES ENVIRONMENT

72. Although logically a discussion of stresses on the environment should preceed a discussion of environmental responses, we have by reversing the order of presentation emphasized the response side of STRESS to focus attention on the sorts of environmental data which need integration with the economic and demographic data. In this section we turn back to the economic and demographic data which portray the causes of environmental transformation--that is the human activities and natural factors which stress the environment.

73. The degree to which one may correlate human activities and environmental transformation depends on the specific concerns. In some cases (e.g., eutrophication), the causes of environmental degredation are reasonably well established. In other cases, particularly in those multiple stressed systems the question of the relationship between human activities and environmental responses becomes somewhat clouded. In this section we describe patterns in economic and demographic data for the lower Great Lakes region to illustrate how such information may be classified in terms of the taxonomy of STRESS.

Population and Aggregate Human Activity

74. The lower Great Lakes region has experienced rapid population growth since the turn of the century. In the Lake Erie watershed, population quadrupled over the period 1900-1970, while in the Lake Ontario watershed the population more than tripled. However, if we marry the individual with technological change, represented by energy use per capita, (i.e. demophoric growth), the increase in human pressures in the lower lakes watershed is even more striking. As shown in Figure 10 demophoric pressure in the lower lakes watershed increased twelve fold over the period 1900-1970.

75. Accompanying this relatively large increase in population (some 18 million people inhabited the lower lakes region in 1970) was the general tendency of population to concentrate in a few highly desirable localities resulting in a magnification of the stress effects on particular, and frequently critical, habitats--e.g. river mouths, bays, and harbours.

76. Land use is also a highly integrated measure of human pressures in the watershed. The general land use pattern is shown in Table 19. Agricultural land comprises more than half of the total land area in the Lake Erie watershed while the agricultural activities in the Lake Ontario watershed comprise less than one third of total land area. More than half of the Lake Ontario watershed is still forested, while forest and woodlands account for only 17% of the Lake Erie watershed.

Generation of Waste Residuals

77. Activity Statistics: The Lower Great Lakes are an integral part of the industrial heartland of North America. The STRESS framework calls for industrial process data particularly from the chemical and heavy industries.

78. Point Source Stresses: The quantities and distribution of point source loadings of toxic materials and nutrients are provided in Tables 20-21. Canada's share of phosphorus loadings to the lower lakes is relatively small (less than 10% of point source inputs), while iron loadings are relatively large (approximately 70%). Further, Canada contributes the bulk of nickel and zinc loadings to the lower lakes, while the oil, copper and mercury contamination comes largely from the United States.

79. Industrial activities accounting for much of the Ontario point source loadings are listed in Table 21. The industries associated with relatively high discharges of nutrients, total dissolved solids and suspended solids are the paper and allied industries, primary metals and chemical industries.

80. Diffuse Source Stresses: With respect to diffuse sources inputs, atmospheric depositions are documented in Table 22. Atmospheric depositions of 504 nutrients and heavy metals are given by watershed. These estimates (taken from PLUARG studies for 1974) indicate that overall contributions from the U.S. are substantially in excess of those from Canadian sources. Diffuse loadings via the watersheds are shown in Tables 23 and 24, these indicate the sources of total nutrients (by country and basin) and pesticides entering the lower lakes.

Permanent Environmental Restructuring

81. Major aspects of environmental restructuring for the lower lakes region are reflected in data on shore line land use and data on drainage of wetlands.

82. Shoreline land use is mainly residential (much of this seasonal) and agricultural. Forested areas account for a negligible percentage of the lower lakes shoreline (Table 25). Shoreline protection data are given in Table 26. The various structures in place (breakwaters and the like), while preventing or limiting the rates of erosion, also alter the nature of the exposed coastline habitat, resulting in less favorable conditions for those biota requiring exposed wave swept zones for their survival. While the percentages are small (except Lake St. Clair) to the extent these structures are located in critical zones, e.g. marsh habitat, the environmental implications can be large.

83. In terms of a pervasisve effect on the lower lakes ecosystem, drainage of marshes and wetlands ranks high. Recently completed surveys by the Ontario Ministry of Natural Resources on the wetland areas of the lower lakes document the relatively sparse wetland areas in the lower lakes, especially in western Ontario (the Golden Horseshoe area) and other heavily populated areas (Figures 11-13 and Table 27). Much of this depletion is well correlated with the expansion of urban areas, and the use of rural areas for agricultural purposes. The latter accounts for much of the recent depletion of marsh lands in the Lake St. Clair region (Table 28). Depletion of marshlands, wide spread in regions of the lower lakes (Table 29) not only reduces the critical habitat for spawning of fish and nesting by aquatic birds, but also reduces the natural absorptive capacity of these habitats to remove from circulation, nutrients and toxins entering the aquatic ecosystem.

Harvesting

84. Harvesting activities in the lower lakes region comprise forestry, agriculture and fisheries. For purposes of the Case Study, only fisheries were considered within the "harvesting" class, since this directly affects the character of the lower lakes aquatic ecosystems.(6) Commercial catch data have already been discussed and these data serve also as indicators of harvesting stress. Documentation of the stress side might in addition include information as to the intensity of fishing effort--e.g. the time that various types of gear are employed in fishing (such as use of gill nets, trapnets, line operations). Unfortunately such data are not yet available for the whole region.

Introduction of Non-native Species

85. Documentation of the introduction of non-native species is provided in Tables 11 and 12. some of these introductions were accidental and resulted from construction of canals (the sea lamprey invaded Lake Erie through the Welland Canal), or escapes from fisheries stocking programs in adjacent small lakes. Other introductions were to control alewife or provide improved sport fishing opportinities.

Natural Geophysical Activity

86. One major influence on the Lower lakes environment is the fluctuations in water levels and precipitation in the region. These fluctuations have considerable amplitude and are irregular in their periodicity, having peaks on the order of a decade or so. It is currently believed that such natural occilations in water levels may account for much of the variation year to year in water quality parameters and in the associated composition of phytoplankton and zooplankton communities.

87. Another factor which has some influence on the lower lakes environment is the rate of natural erosion and associated sediment and nutrient loadings resulting from such erosion processes. The Great Lakes Shorline Damage Atlas (Environment Canada, Ontario Ministry of Environment) provides an indication of areas in the watershed of Lakes Erie and Ontario which are subject to high rates of natural erosion.

IX. ANALYTICAL POTENTIAL OF STRESS

88. The primary function of STRESS is to organize and integrate various data bases within a regional context for purposes of environmental analysis. STRESS thus provides the data base for an overview or state of the environment report documenting major human activities giving rise to environmental transformation, stresses from these activities, and a spectrum of broad based indicators of environmental response.

89. As an aid in the analysis of regional environmental issues, STRESS has a number of potential applications. First, it may function as a check for sufficiency of information relating to complex environmental issues. By structuring economic, demographic and environmental data in a comprehensive framework STRESS serves as a guide to the sufficiency of state of environmental reporting. Within the bureau, for example, STRESS has been used to structure a more comprehensive approach to organization of bureau statistics on human activities as they relate to environment.

90. STRESS permits comparison of different regions with respect to the pattern of human activity and environmental effects. For example, STRESS data might contribute to an analysis of differences in the subregions of the Lower Great Lakes, taking into account the different spectrum of human activities collectively transforming the environments of these subregions.(20)

91. Another application of STRESS would be to provide an information base for analytical models of the environment in an ecosystem context. In rehabilitating stressed environments, a first step is to identify the major factors that have acted to transform the environment and develop a model of the relationship of these factors to the state of the environment. As shown in Table 30, an initial step in the construction of analytical models of this sort is to identify the major forces of stress and determine the extent to which they interact.(21) STRESS could provide information as to the quantitative importance of the human activities that affect a given region.

92. As shown in Table 31, the interactions between stress factors and environmental responses can be very complex--even when only the natural ecosystem responses are considered (with in terms of STRESS represents only a narrow part of the total problem). The notion of the complexity involved is enhanced when one takes into account the time lags, inherent system fluctuations and other factors which appear to defy realistic modeling of these systems at the present time. The STRESS data base, by identifying holistic measures of stress and response factors, may serve to simplify the apparant complexity to a level that can eventually be the basis for more workable models of environmental change.

X. STESSS IN A POLICY CONTEXT

93. The primary role of STRESS in a policy context would be to serve as a data base to assist planning and evaluation of the state of regional environments. In this context, STRESS relates to policy initiatives for the Great Lakes as portrayed in Figures 14-15. STRESS can be viewed as a statistical data base germane to a wide variety of Great Lakes perspectives (Figure 14). This is the case since STRESS was designed to incorporate a number of features important to an ecosystem approach to rehabilitation of environment (Figure 15).

94. How might a data base organized around STRESS best serve in the context of the Great Lakes current policy and strategy initiatives? The stated overall objective of the 1978 Water Quality Agreement commits the parties (the United States and Canada) "to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem". The actions of IJC thus far have concentrated on the chemical aspects of the system, setting standards for the maximum concentrations of toxic substances, and nutrients. The use of a STRESS information base would also point to the need for emphasis in other areas--particularly with respect to physical restructuring and overharvesting. Further, a STRESS framework would broaden the analysis to consider explicitly the types of human activities responsible for changes in the environment.

95. By developing a set of environmental indicators that provide an overview of different facets of the Great Lakes environment, STRESS may enable decision makers to better assess the process of environmental transformation and determine the extent to which stated objectives of the international agreements were in fact being approached. Currently, it would appear that year to year fluctuations in the nutrient and toxic chemicals in the lakes are of major concern to IJC, while no concerted effort is being made to determine the overall trends in the state of the Lower Lakes environment.

XI. SUMMARY

96. The lower Great Lakes Case Study was designed to meet several major challenges to the further development of environmental statistics patterned in terms of the structural framework of STRESS. These challenges included questions of the availability of data to represent the concepts fundamental to STRESS; the quality of such data, particularly on the response side; potential analytical uses of STRESS; and the interface of STRESS and environmental policy.

97. The Case Study provided an opportunity to consider these questions in a specific geographical context--The lower Great Lakes, a region chosen both for its environmental significance and for the abundance of data already available on many aspects of environmental concerns. For this region, there does exist considerable data on the major elements of STRESS, particularly on the human activities side. However, it cannot be denied that the response data are somewhat less developed, but nevertheless they do provide sufficient information to portray the major dimensions of environmental change.

98. The major analytical use envisioned for STRESS would be to facilitate a broad assessment of the state of regional environments. Heretofore, while there has been interest in such assessments, insufficient attention has been given to the critical task of selecting environmental indicators which could be used to gauge the effectiveness of environmental policy.

XII. CONCLUSIONS

(1) Availability of Economic, Demographic, and Environmental Data. Originally it was questionned as to whether data exist in sufficient detail to document realistically the concepts underlying STRESS. As shown in the Case Study, existing data can be obtained even at this stage to provide an outline of the STRESS framework. Quite clearly there is a need to

develop further certain aspects of the data base implied in the framework. Economic and demographic data serve to document major human influences that have transformed this region. Envirionmental responses to human pressures are portrayed in terms of a set of indicators that document not only changes in the levels of contamination, but also basic changes in aquatic ecosystem productivity, nutrient status, and the quality and composition of the biota.

(2) Quality of data. Data on the stress side, particularly population trends, harvesting, and industrial production, are for the most part available from well established time series, although in some cases require better geocoding to relate to particular environmental regions. However data on land use, pollution loadings, and physical restructuring are currently obtained from adhoc studies and required further development to establish consistent and comprehensive time series. Data on the response side are still more embrionic in character. In some aspects, particularly data relating to changes in composition of biota, depletion of wetlands, contaminants in biota and sediments existing data provide adequate coverage. In other aspects, (e.g. primary productivity, primary biomass, nutirent concentrations and turnover) further developments in methodologies for sampling and data processing will be required.

(3) Capability of Environmental Indicators to Reflect Environmental Transformation. The Lower Great Lakes have undergone enormous changes over the past 150 years. Fundamental shifts in the composition of the dominant species in the aquatic ecosystem, have occurred. These changes have in general been to the detriment of the nearshore fisheries, comprising the more valued fishery. Further, contamination of the sediments and the biota is a serious problem for the region. Indicators of productivity and nutrient status reflect in a general way a rather dramatic increase in eutrophication of the Lower Lake. This change in nutrient status, of course, has profound implications for the composition of the biota, as well as for many of the recreational uses of this area. Recognizing these broad transformation trends it is evident that the quantitative measures serve to provide only a general impression of environmental transformation. Quite clearly we are yet at the very early stages of selection and development of environmental indicators.

(4) Flexibility of STRESS. The capability of adapting the STRESS taxonomy developed in the case study to a variety of problem contexts and to various ecosystems including terrestrial systems is becoming more apparant as we gain experience in these areas. With reference to the Lower Great Lakes, the major stress elements that appear to have affected certain regions (Green Bay, Inner Bay at Long Point, and Bay of Quinte) fit readily within the general taxonomy of stresses developed within the case study. Further the response taxonomy, although developed specifically with reference to aquatic systems, is in its broadest sense applicable to other regions, including terrestrial systems.

(5) Ambiguities in STRESS taxonomy. The case study helped to clarify some of the difficulties found in the STRESS taxonomy. For example the role of population and aggregate industrial activities is viewed as a general human pressure on the environment, a perception particularly germiane to a watershed context in which diffuse human pressures provide an aggregate

purturbation on the aquatic ecosystems. Another difficult area is harvesting activity. In classifying such activity with an aquatic ecosystem focus, only harvesting of fishes were entered directly in to the data base. The impacts of harvesting of forestry and agriculture find entries through the generation of waste residuals into the aquatic systems. It is recognized that in terrestrial system focus, these activities would be recorded as direct harvesting effects on biota and under physical restructuring (e.g. land transformation). Another taxonomic problem involves the classification of passive and active ecosystem response to stress. For example, how does one consider the concentration of contaminants in the ecosystem--as a stress, or as on a primary ecosystem response (albiet primarily passive). We arbitrarily opted for the latter, recognising that secondary responses, (e.g., oxygen depletion, species composition changes, etc.) would follow as a result of the elevated nutrient status of these systems.

(6) Models establishing linkages between human activities and environmental transformation. While it is recognized that it would be highly desireabl for development of policy to know the linkages between human activities and environmental transformation, this is yet a long way from being realized in multiply stressed systems such as the Lower Lakes. To be sure there are already partial models, establishing linkages between specific stresses and responses such as between phosporus loadings and eutorphication, or between generation of waste residuals and contamination of biota For development of more comprehensive models, the initial steps involve ascertaining the qualitative interactions among the dominant stress factors and then relating the major stress interactions to ecosystem responses. Further work would proceed to estimate the quantitive relationships between these variables. STRESS might contribute to these developments by providing time series on both stress and response indicators on a regional basis. Regression analyses (or principle components analysis) involving both time series and cross sectional data may then serve to establish some of the dominant linkages between clusters of human activities and environmental transformation.

(7) Applications of STRESS. In the first instance, STRESS may serve as a check for sufficiency for state of environment reporting. The case study documents on a regional basis, a spectrum of response indicator and a taxonomy of human activites that collectively serves to yield a statistical picture of environmental transformation. Many state of environment reports, including some recent country submissions to the OECD reflects the general bias towards concentration on documentation of pollutants in the environmental media - air, land, and water. This aspect of environmental change forms only a part of a comprehensive set of indicators of environmental transformation. STRESS (due to the experience of the Case Study) has already established a Canadian position at the OECD of the desirability, if not yet the feasibility, of approaching environmental indicators from a more holistic perspective, including ecological parameters such as composition of biota, changes in quality of biota, and nutrient status.

(8) The second application of STRESS follows directly from the first. That is, in environmental policy attention is too often focussed on "policing" actions for environmental contamination, at the expense of the broader objective of maintaining the integrity of biological systems. It is possible that the STRESS data base would contribute a more balanced view of the process of environmental transformation.

XIII. FUTURE DIRECTIONS

99. Two proposals are suggested for further work towards an implementation of STRESS. The first involves identification of the different archetypal kinds of ecological/environmental regions of Canada, their major indicators of state (and change of state) of the environment, and the human activities serving to transform the region. The second involves more attention to the impact of environmental change on human activities and well-being --an aspect of the framework for STRESS which by and large has not been dealt with in the case study.

100. The first project might be integrated with ongoing work in Environment Canada on land classification and on state of the environment reporting. The areas already established by the work on ecological (biophysical) land classification provide a possible geographical basis for STRESS. To determine a minimally sufficient set of environmental indicators (for which data already exist or can be readily obtained from existing monitoring capabilities) for each designated environmental region, it is envisioned that various working parties will be established on a federal and regional basis. This work could contribute to a state of the environment report for Canada by 1983.

101. The second project appears more difficult as it involves first a search for appropriate frameworks for indicators of the human effects of transformations in the environment. These potential effects would include health, economic, recreational and a esthetic considerations. The research thrust would be first aimed at the further development of the conceptual framework to include indicators of social impacts of environmental transformation.

Footnotes

1. Statistics Canada. Human Activity and the Environment. Cat. 11-509E. Occasional (1978).

2. Towards a Comprehensive Framework for Environmental Statistics. Statistics Canada (Catalogue 11-510), 1979.

3. Statistics Canada (Cat. 11-510) op. cit.

4. One possible solution is to account for the stress element in exports and imports. Thus, for each region a trade balance with the "rest of the world" might be established in terms of the stress content of goods and services.

5. Note land use in the watershed context was taken as an aggregate indicator with respect to changes in the aquatic ecosystem.

6. For purposes of the case study, harvesting of agriculture and of forests's taken into account only in terms of waste residuals (both nutrients and toxins) that enter the watersheds as a diffuse loading.

7. The "introduction of exotics" category refers to changes in the biota of the aquatic ecosystems, particularly fishes which were not native to the region. These introductions could be considered a consequence of more basic activities, such as Permanent Environmental Restructuring, Climatic changes, Harvesting activities (particularly those associated with fish stocking) etc. However, due to the importance of this type of perturbation for the Great Lakes, a special category was included to reflect this source of transformation regardless of anticedent primary cause.

8. Elaborate statistical programs which transform data collected on water quality parameters such as chlorophyll a, phosphorus, total dissolved solids, have been developed by the Canadian Center for Inland Waters in an effort to reveal trends in Lake Ontario's offshore waters. Similar programs are now being developed for the Lake Erie data by CCIW.

9. G. R. Francis, J.J. Magnuson, H.A. Regier and D.R. Talhelm. Rehabilitating Great Lakes Ecosystems. Great Lakes Fishery Commission Technical Report / 37. December 1979. 99pp. ; W.L. Hartman. Lake Erie: effects of exploitation, environmental changes, and new species on fishery resources. J. Fish. Research Board Canada 29: 899-912; A.M. Beeton. Changes in the environment and biota of the Great Lakes. pp 150-187 in Eutrophication: causes, consequences, correctives. Nat. Acad. Sci., Washington D.C. 1969.

10. Magnuson, J.J., H.A. Regier, W.J. Christie and W.C. Sonzogni. To rehabilitate and restore Great Lakes ecosystems, pp 95-113. in: J. Cairns Jr., Ed. The Recovery Process in Damaged Ecosystems. Ann Arbor Sci Publ., 1980.

11. Beeton suggests that historically, offshore waters of the Lower Lakes for depths greater than 15 meters had values of less than 4ug/l of chlorophyll a. See A.M. Beeton, op. cit.

Footnotes - Concluded

12. For example, oxygen depletion is in part responsible for the demise of fish species requiring the cool bottom waters for as mid-summer refuge. Oxygen depletion at the mouths of streams may effectively block off these arease from fish spawning migrations.

13. H.A. Regier and W.L. Hartman, "Lake Erie's Fish Community: 150 Years of Cultural Stresses", Science, Volume 180, pages 1248-1255, 1973.

14. Commercial fisheries in both Lower Great Lakes from 1879 until approximately the turn of the century were concentrated on the accessible nearshore species consisting of large benthic fishes such as lake whitefish, sturgeon, sauger, and carp (in L Erie). Small pelagic fishes did not enter the commercial catch in significant quantities until 1897. In lake Ontario, a similar pattern prevails--with fishing concentrated on large benthics initially and selected large pelagics (1 herring). Only at the turn of the century with the development of the yellow perch fishery were small pelagics fished. In 1952, partially as a result of changes in fishing gear, (small pelagics) entered the commercial catch in significant quantities.

15. N.A. Thomas and W.J. Christie. 1979. Status of the Biota of Lake Ontario during KFYGL. International Field Year for the Great Lakes.

16. IBID.

17. At the same time, the total catch in both lakes has risen somewhat Further, the dollar value of the catch also increased, reflecting both an increase in quantities taken and the general inflationary patterns. The dollar value of the total Canadian catch in 1953 in Lake Ontario was $260,000 whereas in 1977 the value was $941,000. Comparable figures for L. Erie were $3.0 million and 5.1 million.

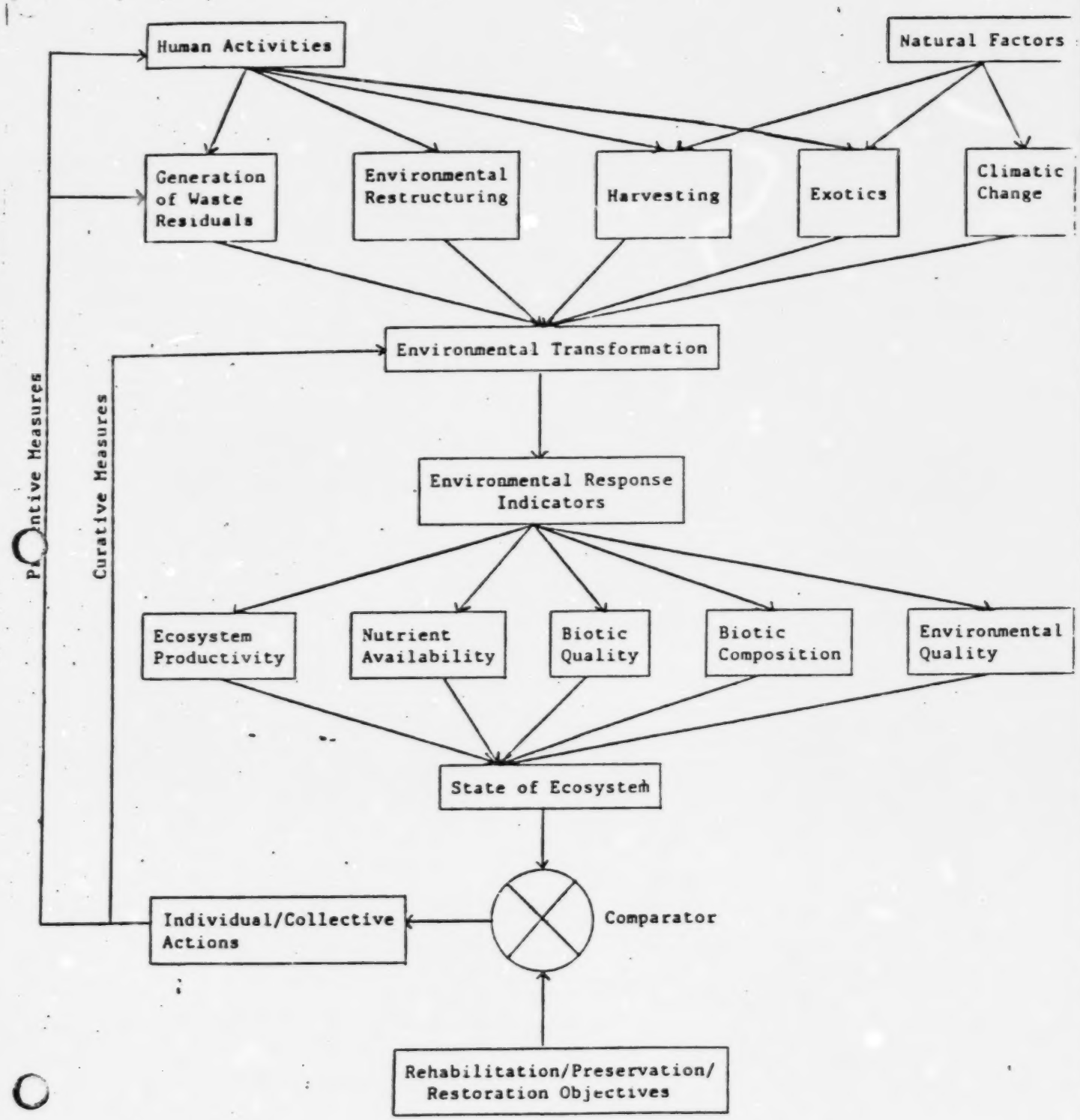
18. See for example, Health and Welfare Canada and Statistics Canada 1980. The Mortality Atlas of Canada. Vol. 1. Cancer cat. H49-6-1-1980. ISBON-660-50443-X.

19. Address by W. Swain, to International Association for Great Lakes Research, Kingston, Ontario. May, 1980.

20. A comparison of the modifications that occurred in the ecosystems of Toronto Harbour with Inner Bay of Long Point would of course have to account for the different types and intensities of stresses in these regions. STRESS data, if sufficiently detailed to give small area information would contribute to the overviews of these regions and provide a point of departure for more detailed analysis.

21. See for example the models developed for Green Bay (L. Michigan) and the Bay of Quinte (Lake Ontario). These analytical models are given in: G. Francis et al. 1979. Rehabilitating Great Lakes Ecosystems. Great Lakes Fisheries Commission. Technical Report /37. December 1979. 99pp.

FIGURE 1. Main Elements of Case Study



Source: Case Study Elaboration of Chart 1, page 64, S.C. Cat. 11-510.

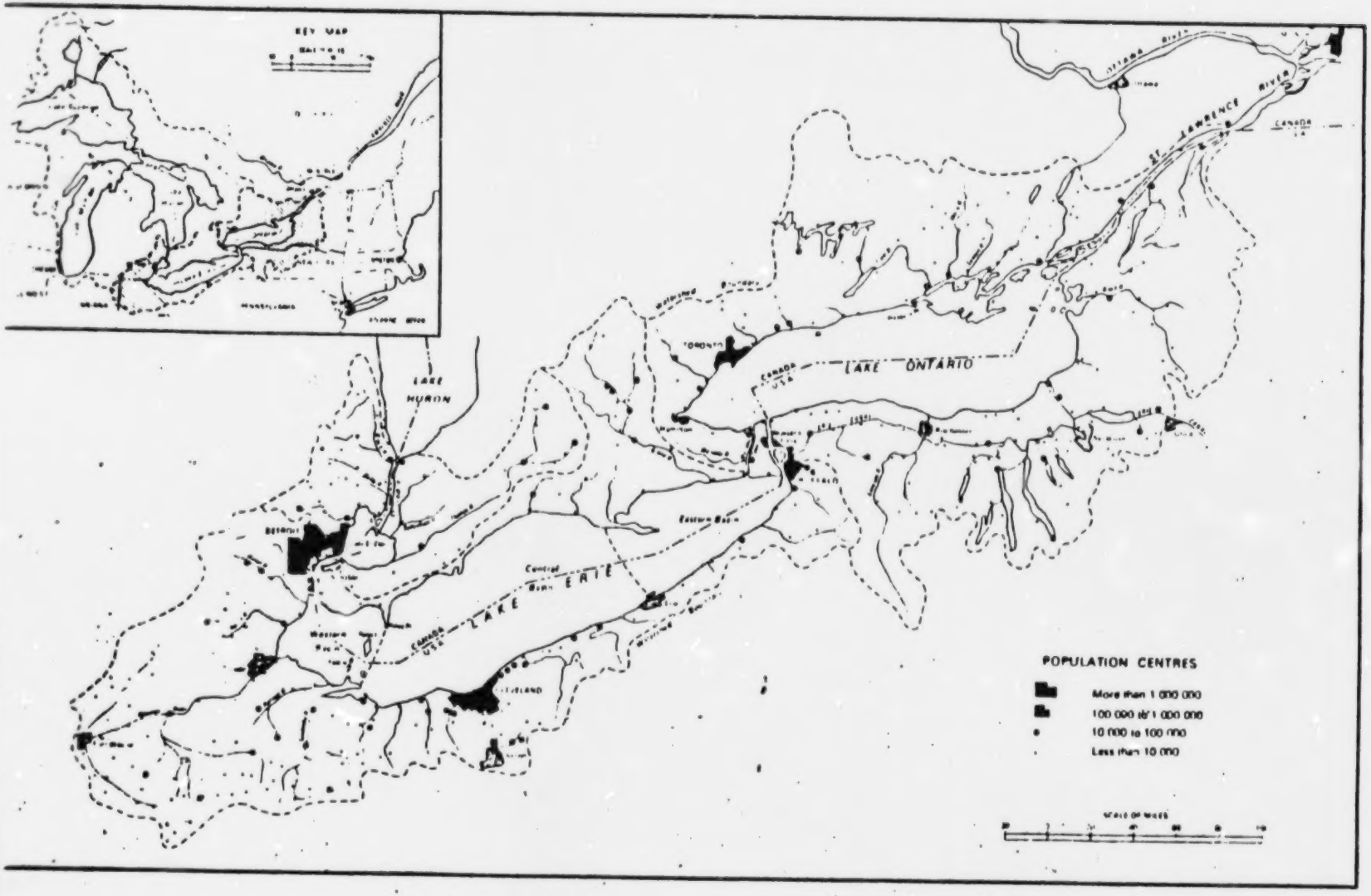


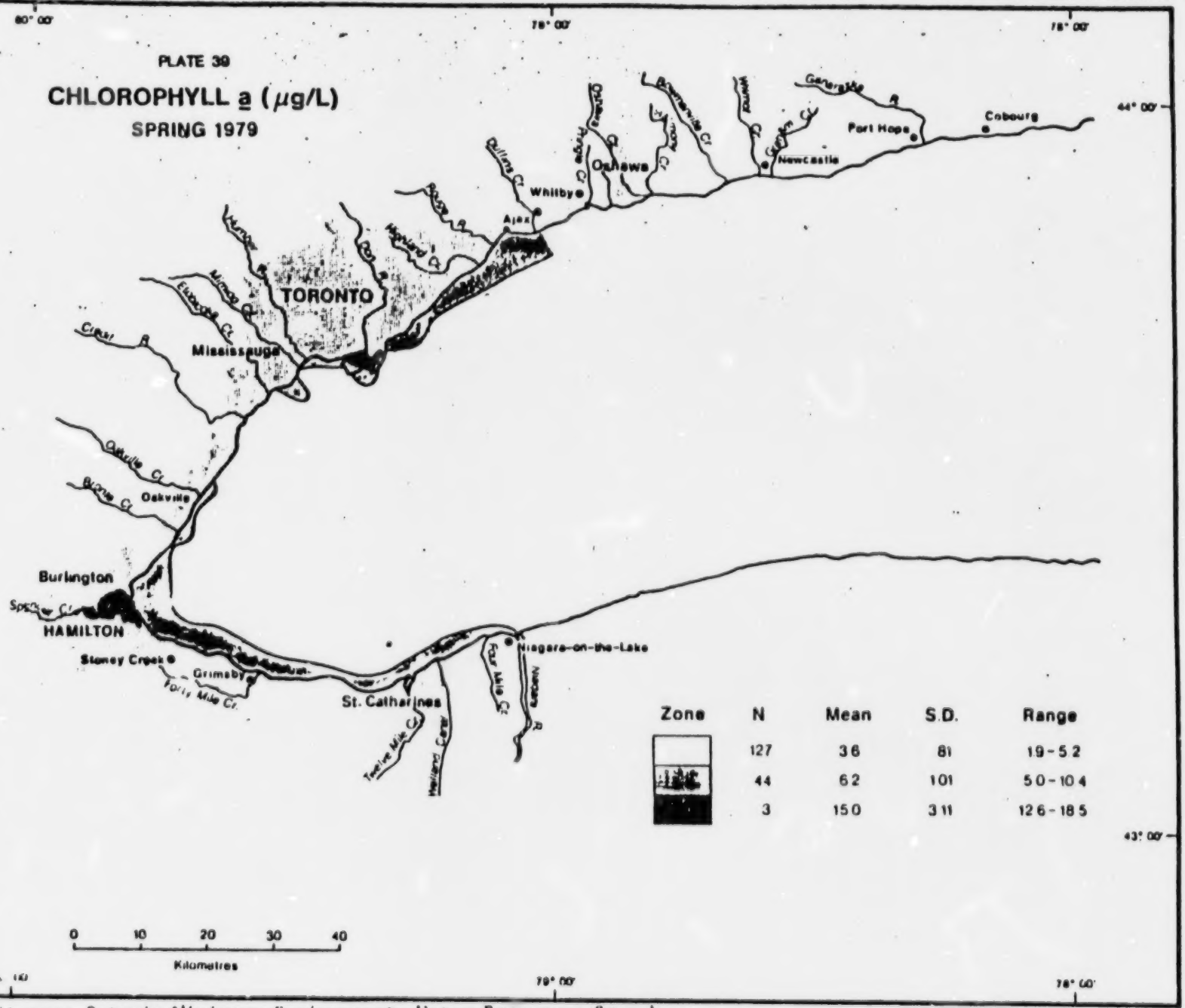
Fig. 2. Lake Erie and Lake Ontario drainage basins.

source: IJC

PLATE 39

CHLOROPHYLL a (μg/L)

SPRING 1979

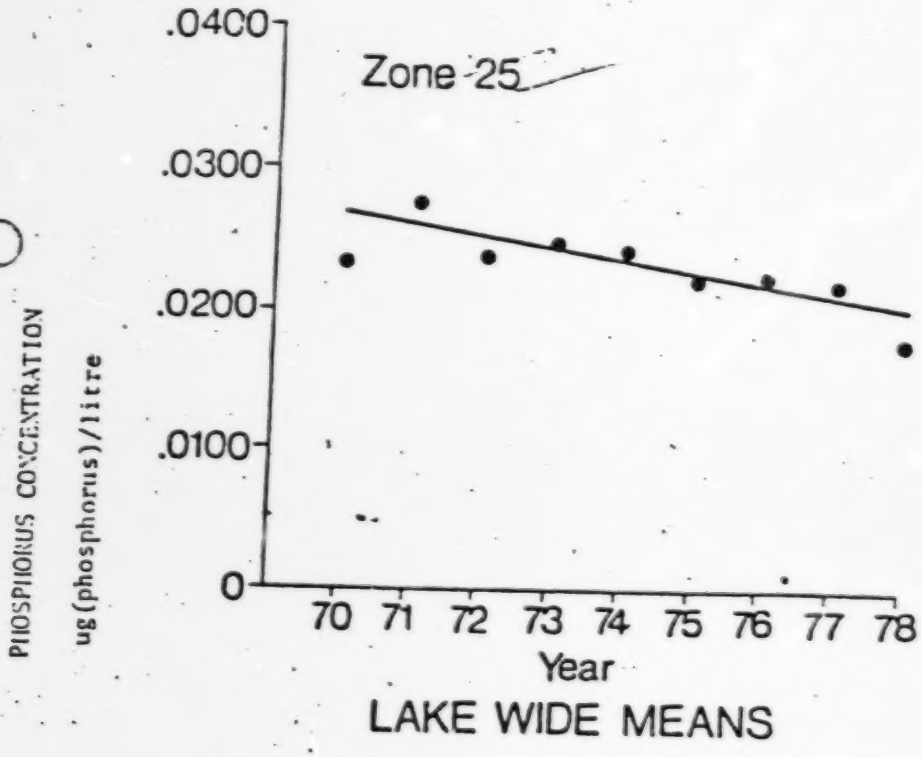


Source: Ontario Ministry Environment, Water Resources Branch

FIGURE 4

TOTAL PHOSPHORUS TREND IN LAKE ONTARIO.

VOLUME WEIGHTED SPRING MEAN CONCENTRATIONS.



Source: Canada Centre for Inland Waters. Data supplied by A.S. Fraser.

Note : The downward trend is most dominated by the 1978 data point. The relationship of this apparant trend to remedial programs for the reduction of phosporus loadings is examined in "Changes in Lake Ontario Total Phosphorus Concentrations, 1976-1978. Journal Great Lakes Research (in press).

Figure 5.

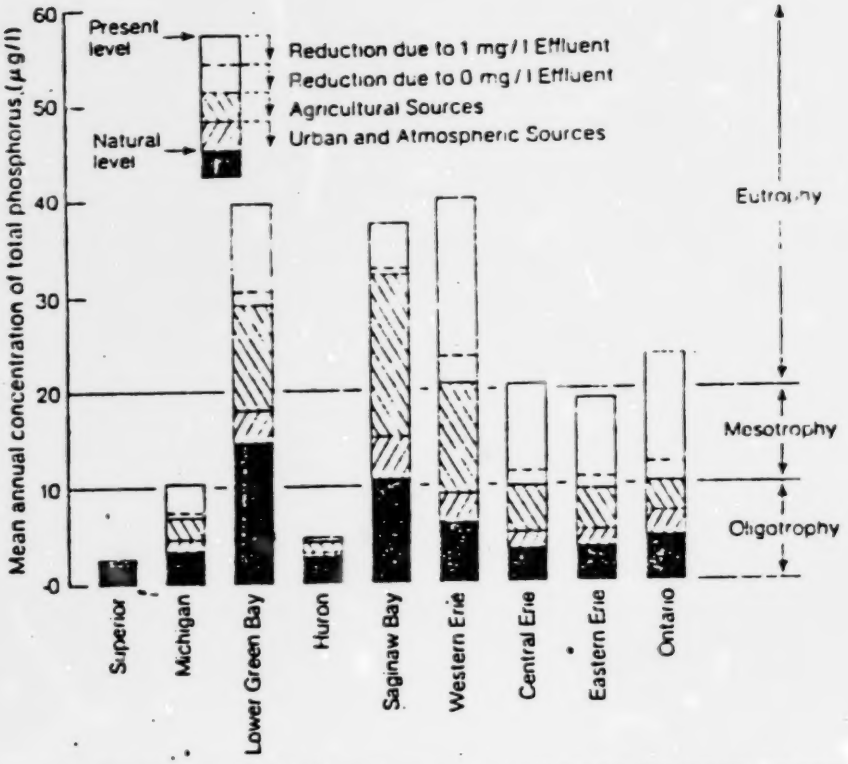


Fig. 1. Total phosphorus concentrations (micrograms per liter) resulting from various treatment schemes for the Great Lakes.

Source: S.C. Chapra and A. Robertson, 1977.
Great Lakes Eutrophication: The Effect of Point Source Control of Total Phosphorus. Science 196: pp. 1448-49

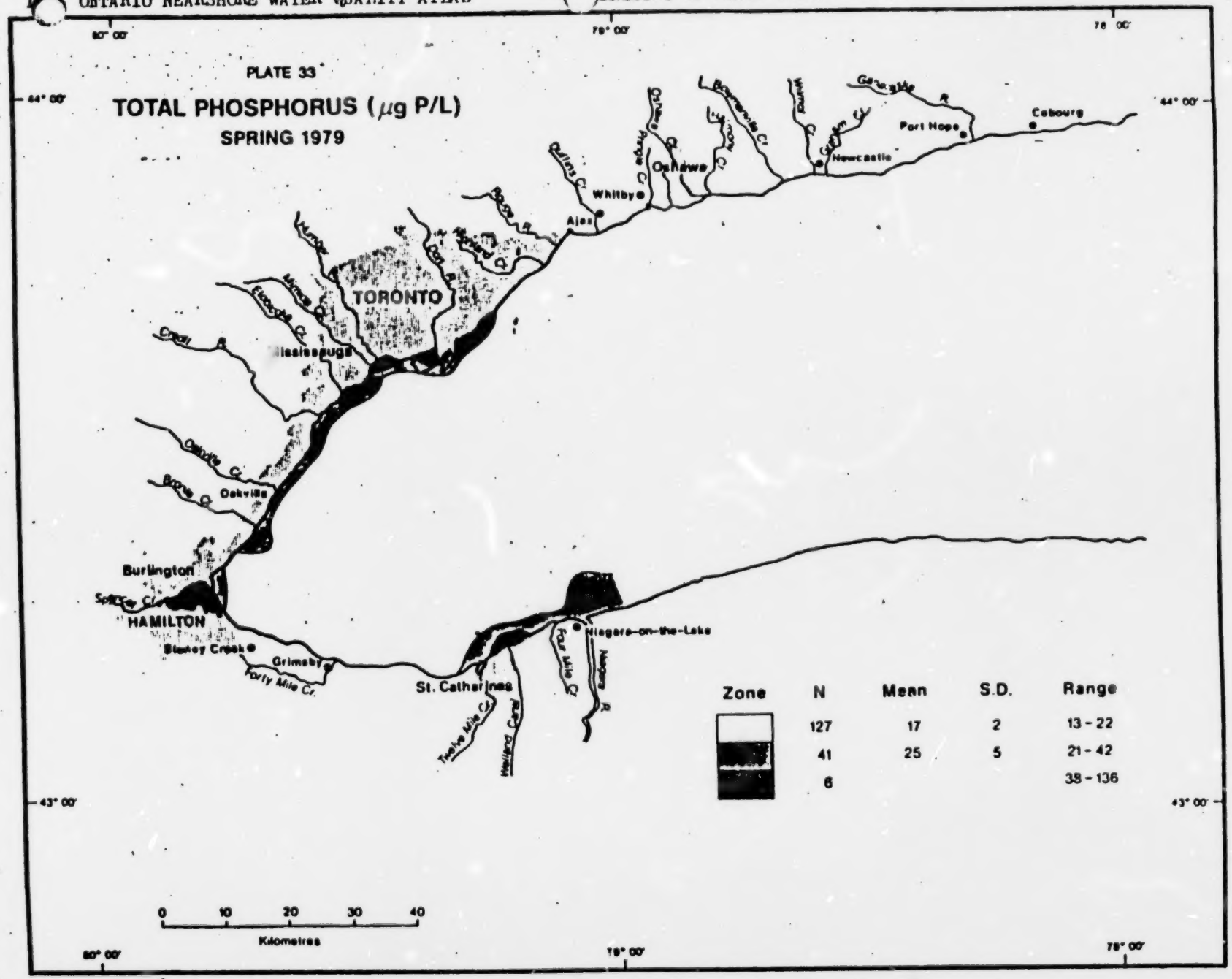
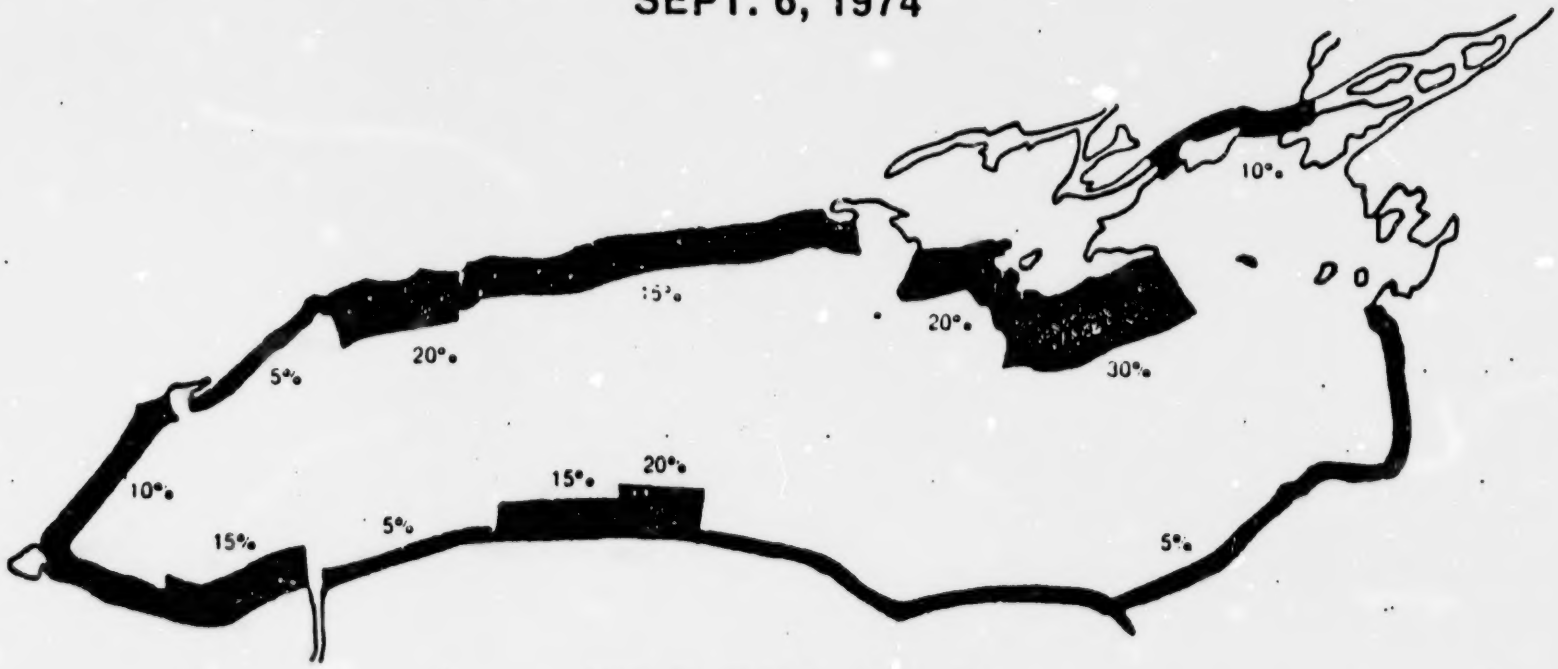


Figure 6. Total Phosphorus Spring Survey, Canadian Nearshore, Lake Ontario, 1979
Source: Ontario Ministry of Environment, Water Resources Branch

PERCENT OF SHORELINE WITH *CLADOPHORA* ACCUMULATIONS SEPT. 6, 1974



Miles observed at 5% — 191
10% — 66
15% — 90
20% — 43
30% — 25
Total observations — 415 miles

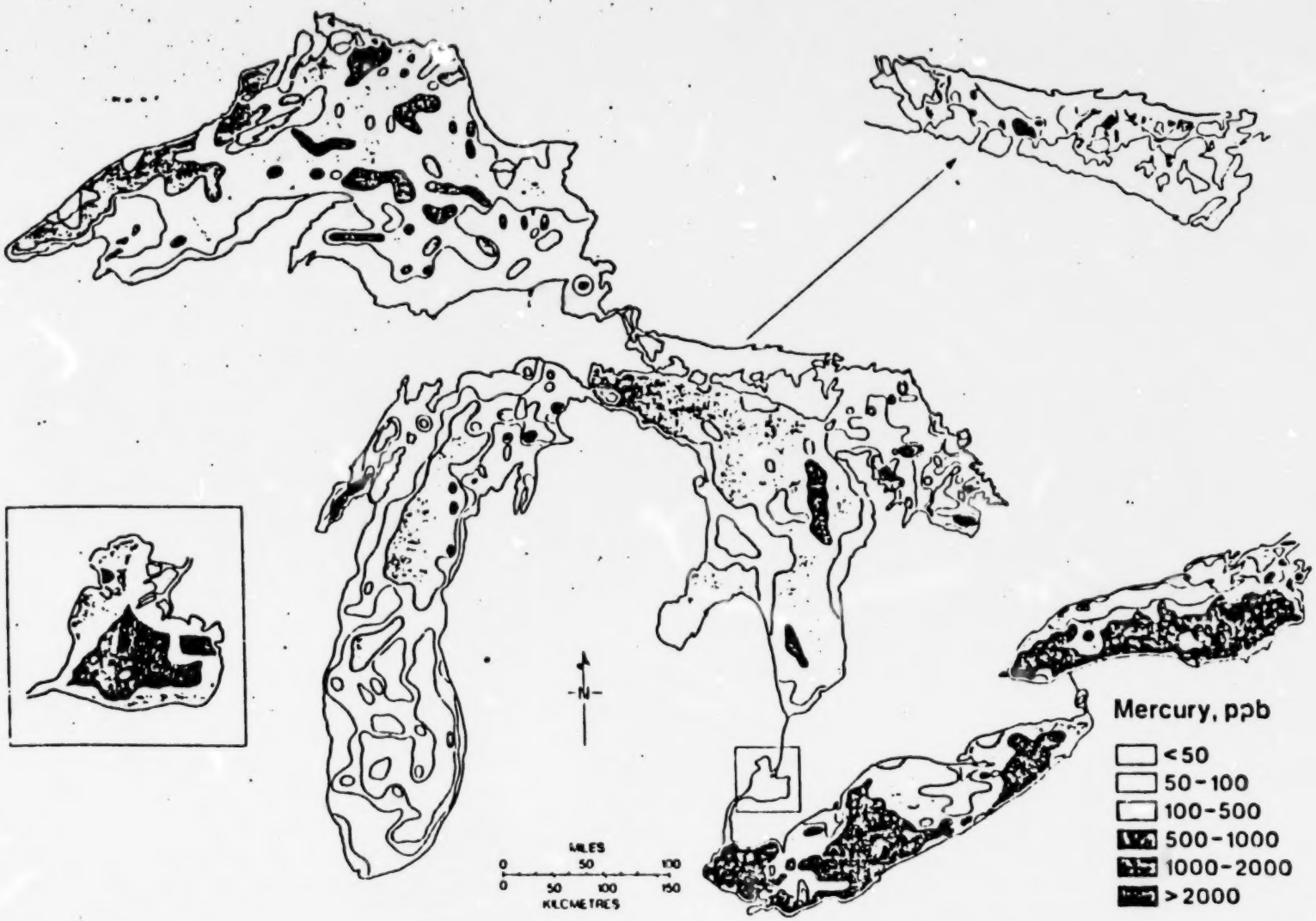


Fig. 8. MERCURY CONCENTRATIONS IN SURFACE SEDIMENTS OF THE GREAT LAKES (ppb = µg/kg).

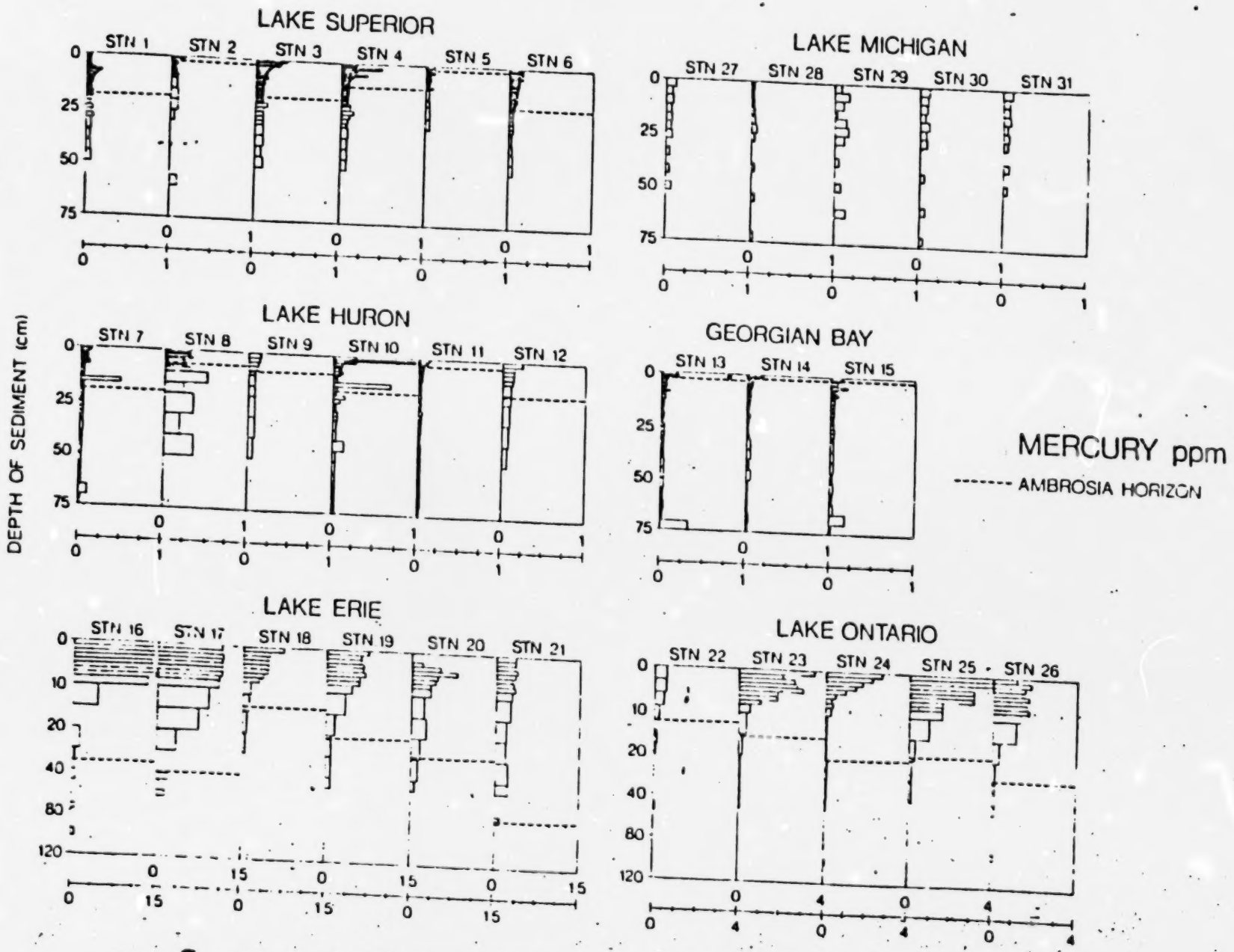


Figure 9 Source: Canada Centre for Inland Waters, data supplied by R. Thomas

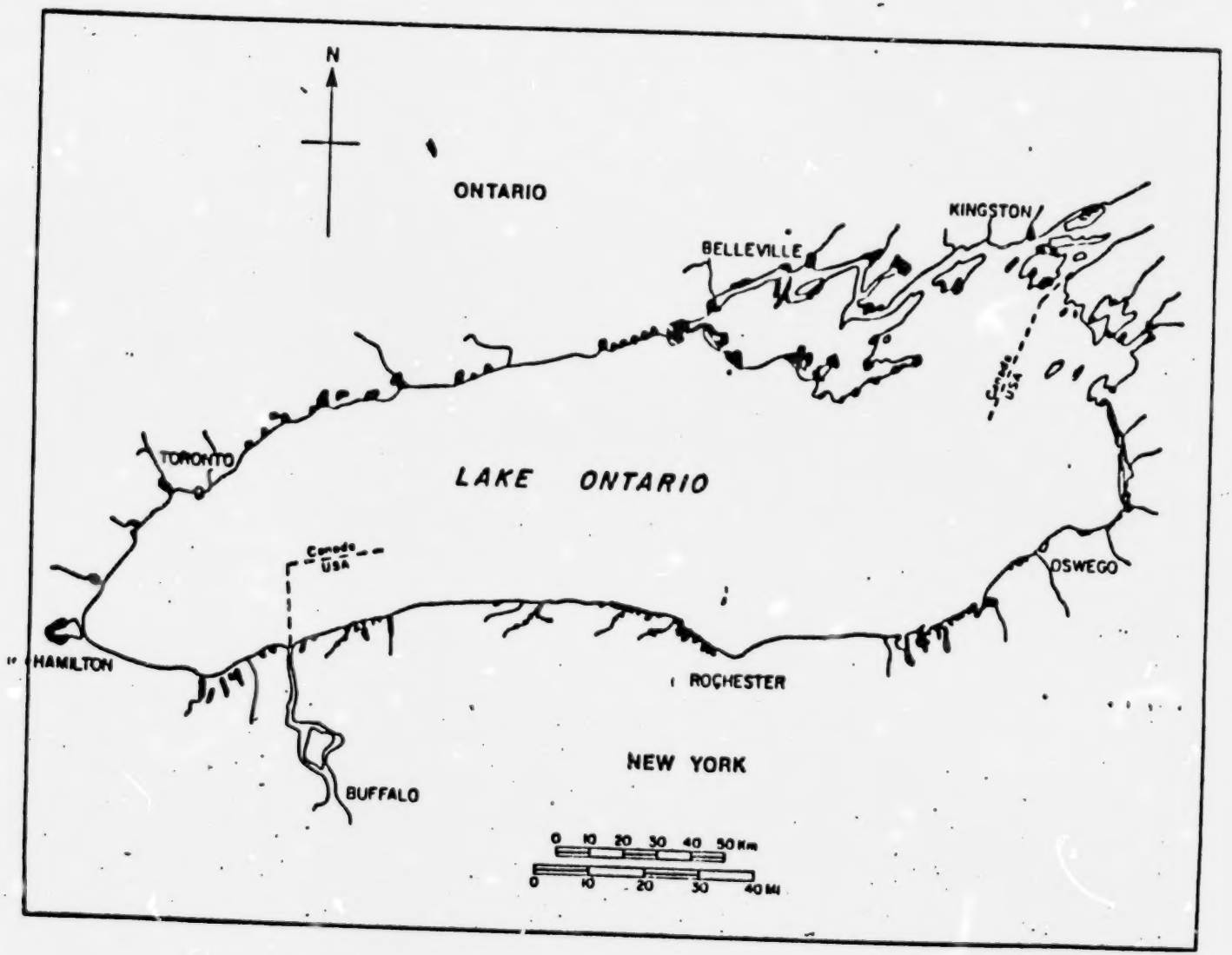


Fig. 11 Wetlands of Lake Ontario Source: Canadian Wildlife Services, London Ont.

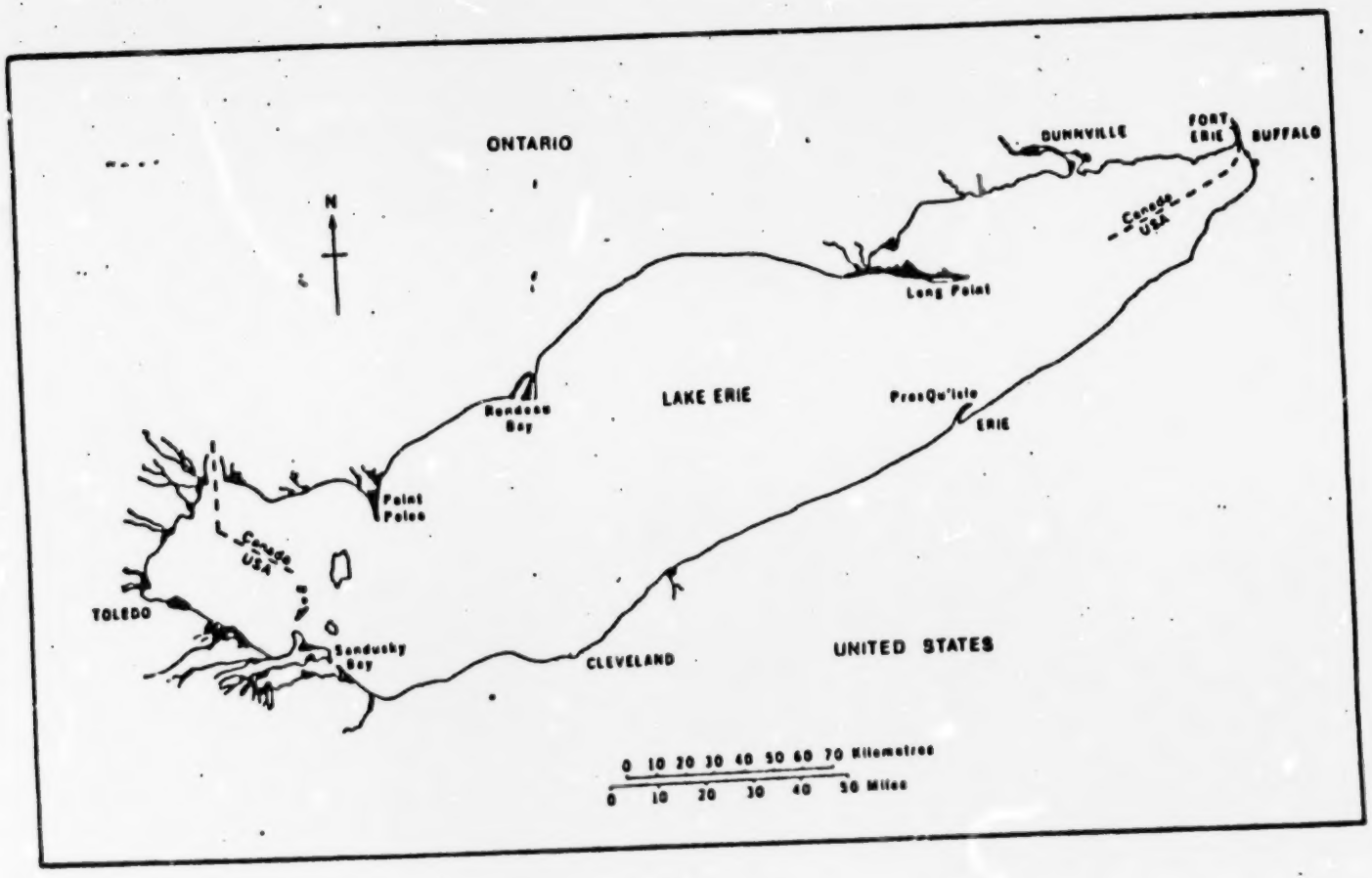


Fig. 12 Wetlands of Lake Erie

Source: Canadian Wildlife Services, London Ont.

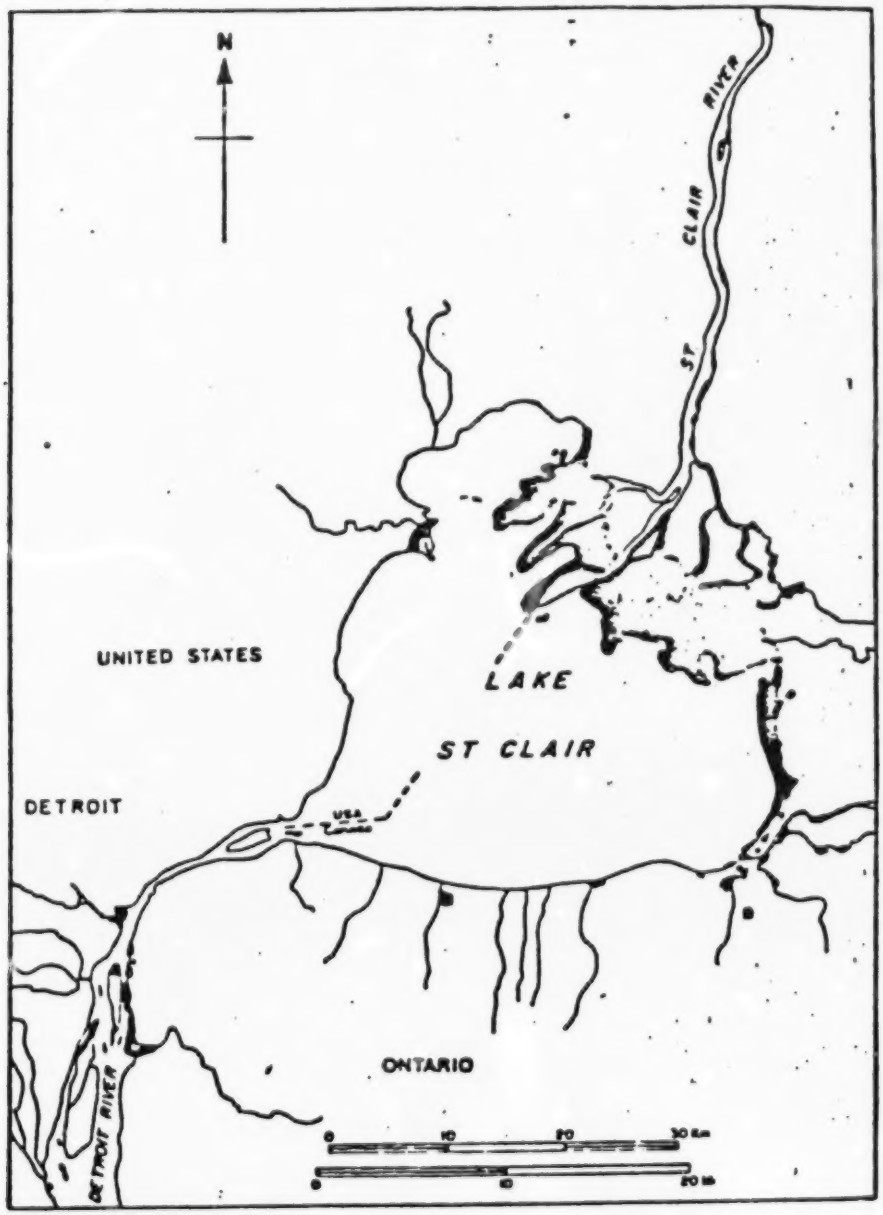


Fig.13. Wetlands of Lake St. Clair.

Source: Canadian Wildlife Services, London Ont.

CRITERIA	APPROACH									
	I.J.C.'s Ecosystem Approach	Great Lakes Megalopolis	GLER (Rehabilitation)	SPOF (Ontario Fisheries)	Lake Trout Ecosystem Indicator	McHarg's GIPS Method	PLUARG (Land Use Pollution)	ESA Planning	GLEAM (G. Lakes Models	S-RESS (Environ Statistics)
Primary emphasis is on ecological phenomena.	●	○	●	●	●	●	●	●	●	●
Boundaries reflect ecological integrity.	●	◖	●	●	●	◖	●	●	●	●
Mapping, monitoring and modelling are used to assess ecological state and processes.	◖	○	●	●	●	◖	●	●	◖	●
Ecological self-regulation is considered.	●	○	●	●	●	○	●	●	●	●
Ecological responsiveness is considered.	●	●	●	●	●	●	●	●	●	●

● Criterion is used.
◖ Criterion is partially or inconsistantly used.
○ Criterion is not considered.

FIG. **14.** *Ecological criteria for an "ecosystem approach"*

Source: B.J. Lee et al. 1980. Ecosystem Management Strategies for the Great Lakes and Their Basin. Insitute for Environmental Studies. U. Of Toronto. Working paper. 52pp. Fig. 6, p.42.

	PLANNING CRITERIA	APPROACH									
		I.J.C.'s Ecosystem Approach	Great Lakes Megalopolis	GLER (Schaut's extension)	SPOF (Ontario Fisheries)	[illegible]	Manders's CAPS Method[a]	PLUARG (Land Use Pollution)[b]	ISA Planning	[illegible]	S-RESS (Environ. [illegible])
SYSTEM GOALS	Maintenance of a minimum level of ecosystem quality	●	●	●	●	●	●	●	●	●	●
	Optimization of diversity within ecosystems	○	○	●	●	▲	●	●	●	○	●
	Optimization of diversity between ecosystems	○	○	●	●	○	●	○	●	○	●
	Maintains the ecosystem's natural variabilities	○	○	●	●	●	○	○	●	○	●
SYSTEM RESOURCES	Best current scientific information	●	●	●	●	●	◗	●	●	●	●
	Planning for management programs	○	○	●	●	○	●	●	●	○	○
	Public understanding and support	●	●	●	●	○	●	●	●	○	○
SYSTEM COMPONENTS	Important ecosystem resources and indicators of health	●	○	●	●	●	◗	●	●	●	●
	Cultural activities which stress the ecosystem	●	●	●	●	●	●	●	●	●	●
SYSTEM MANAGEMENT	Adaptive, experimental management	○	○	●	●	●	▲	◗	●	○	●
	Monitors human activities and ecosystem indicators	○	●	●	◗	●	◗	●	●	●	●
	Attempts to communicate management alternatives	●	○	●	●	○	●	○	○	●	●
	Separates ecological options from value judgements	○	○	▲	▲	▲	●	▲	▲	●	●
	Considers translation into administrative regulations	●	●	●	●	○	●	●	●	●	○
	Avoids or attempts to prevent large scale ecosystem change	●	○	●	●	●	●	●	●	◗	●
	Uses a safety factor	●	○	●	●	○	◗	○	●	◗	○
	Outlines specific direction for research	●	○	●	●	●	●	●	●	●	●
OTHER CONSIDERATIONS	Has or recommends a self-reviewing evaluationary structure	○	●	○	○	○	◗	●		▲	○
	Designs a just resource allocation system	○	○	○	●	○	○	○	○	○	○
	Attempts to resolve multi-use conflicts	○	○	○	●	○	●	●	○	○	○
	Addresses regional distribution of uses and benefits	○	○	○	○	○	○	●		○	○

Fig. 15.

Planning criteria for an "ecological approach"

Source: B.J. Lee et al. 1980. Ecosystem Management Strategies for the Great Lakes and Their Basin. Institute for Environmental Studies, [illegible]

TABLE 1. Structural Framework for the Stress-Response Environmental Statistical System (STRESS)

Environmental Concern Category	Activity Statistics	Stress Indicators	Environmental Response Indicators	Collective & Individual Response	Inventory of Stock
I. Population*	Population change on temporal and spatial plane	Population in relation to carrying capacity	Environmental Quality Indicators	Control of population growth and habitat	Census of populations*
II. Generation of Waste Residuals*	Production and consumption of economic commodities*	Point-source and transport pollution loading in environmental media*	Ecosystem Health* Human Health*	Actions to reduce pollution loadings*	Pollution abatement and recycling capacity*
III. Environmental Contamination*	Production, disposition & disposal of potentially hazardous substances*	Leakage of P.H.S. in env. Application of P.H.S.*	Levels of Environmental Contamination* Rates of Regeneration of Renewable Resources	Action to control the use of P.H.S.	Stock of P.H.S.
IV. Permanent Env. Restructuring inclusive of Transport Networks/Technology*	Construction Activity and Land Use Change*	Location of construction activity and land use change*	Sustainability of Harvests	Actions to Protect and conserve environmental assets*	Accumulated stock of man made structures, Land use Inventories*
V. Harvesting and Extraction of Renewable Resources*	Production from renewable resources*	Exploitation rate and technological stresses, species introductions, diffuse loadings*		Actions to control technology and establish harvest quotas	Stock of renewable resou
VI. Natural Geophysical Activity*	Climate, physical events*	Floods, droughts, earthquakes, tidal waves, natural contamination*		Expenditure Incurred to protect against extreme "natural events"	Mapping of climates, geophysics
VII. Energy*	Production, use and distribution*	Thermal loadings, noise (acoustic energy), Energy Infrastructure*		Energy conservation	Energy Infrastructure and networks
VIII. Depletion of Non-Renewable Resources	Ratio depletion rates to proven resources, substitution, exploration			Conservation measures	Stock of non-renewable resources, Proven Resources of non-renewable

* Indicates elements of the case study.

Source: Catalogue 11-510, Towards a Comprehensive Framework for Environmental Statistics; A Stress-Response Approach, (1979); Office of Senior Advisor on Integration. Statistics Canada, Modified Text Table 1, p. 80.